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Title of the Thesis : Creation of an Orderly Jet and Thrust Generation in Quiescent Fluid from an Oscillating Two-dimensional Flexible Foil

Abstract

In nature, many of the flapping wings and fins in swimming and flying animals have various degrees of flexibility with strong and coupled solid-fluid interactions between the structure and the fluid. In most cases, the wing structure, the flow and their interactions are complex. This thesis experimentally investigates a 'simple' fluid-flexible foil interaction problem: flow generated by a pitching foil with chordwise flexibility.

To explore the effect of flexibility on the flow, we study the flow generated in *quiescent* water (the limiting case of infinite Strouhal number) by a sinusoidally pitching rigid symmetrical NACA0015 foil to which is attached a 0.05 mm thick chordwise flexible polythene flap at the trailing edge. The chordwise length of flap is $0.79\,c$, where $c = 38$ mm is the chord length of the rigid foil; span of the foil and flap is 100 mm. Detailed particle image velocimetry (PIV) and flow visualization measurements have been made for twelve cases, corresponding to three pitching amplitudes, $\pm 10°$, $\pm 15°$, $\pm 20°$, and four frequencies, 1, 2, 3 and 4 Hz for each amplitude.

For most of these cases, a narrow coherent jet aligned along the center-line, containing a reverse Bénard–Kármán vortex street, and a corresponding unidirectional thrust are generated. This thrust is similar to the upward force generated during hovering, but motion of our foil is much simpler than the complex wing kinematics found in birds and insects; also the thrust generation mechanism seems to be different. In our case, the thrust is from a co-ordinated pushing action of the rigid foil and the flexible flap. Control volume analysis reveals the unsteady nature of thrust generation. In this intricately coupled flow generation problem, chordwise flexibility is found to be crucial in producing the coherent jet. In this thesis, we explore in detail the physics of jet flow produced by the foil with a flexible flap, and identify the importance of flexibility in flow generation. Flap motion ensures appropriate spatial and temporal release of vortices, and also imparts them convective motion, to obtain the staggered pattern that produces the jet. To describe the fluid-flap interaction, we conveniently characterize the flap through a non-dimensional stiffness, 'effective stiffness' $(EI)^*$ of the flap, that captures the effects of both the flap properties as well as the external forcing. With the same flap by changing the pitching parameters, we cover a fairly large $(EI)^*$ range varying over nearly two orders of magnitude. However, we observed that only moderate $(EI)^*$ ($\sim 0.1 - 1$) generates sustained narrow, orderly jet. We provide thrust estimates useful for the design of flapping foil thrusters/propulsors. Although this study has only indirect connections with the hovering in nature, it may be useful in understanding the role of flexibility of bird and insect wings during hovering.

In contrast, a foil with a rigid trailing edge produces a weak jet whose inclination changes continually with time. This meandering is observed to be random and independent of the initial conditions over a wide range of pitching parameters.